N87-20319

BAKING THE FIRST BREAD IN SPACE

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ABSTRACT

The Getaway Special program is a joint venture between Spar, Monarch Flour and Telesat, with Telesat being responsible for the design, manufacture and implementation of the equipment.

The purpose of the experiment is to investigate the behavior of bread yeast in the absence of gravity and in the presence of normal atmospheric pressure. The proposed design mixes flour, water and yeast on-orbit, allows the mixture to prove and then "bakes" it.

This paper outlines the development history of the experiment, the various test programs and some of the problems encountered, with their solutions.

INTRODUCTION

In October of 1983, Spar Aerospace, Telesat Canada and the National Research Council of Canada announced a Canada in Space competition inviting all Canadians to come up with ideas for an experiment they would like to see done in space. The effort was a direct outgrowth of the Getaway Special Program.

While Telesat and the National Research Council sponsored competitions for secondary schools and universities, respectively, Spar chose to invite ordinary citizens to come up with ideas. The notion that experiments in space are not the sole domain of experts and scientists was well proven as 515 entries were submitted to Spar - 91 in the French language.

The criteria for the selection of the experiment were stringent; first and foremost it had to be feasible; it had to be capable of surviving up to eight weeks on the launch pad before liftoff; and it had to be affordable. All entries were reviewed by Spar engineers and then screened by a blue ribbon panel. Finally, in April of 1984 the winning experiment was announced; Canada was going to bake the first bread in space. There were 10 winners in all, coming from Nova Scotia, Quebec, Ontario, Alberta and British Columbia. All had voiced a common scientific curiosity in determining what effects the weightlessness of space would have on yeast.

Once the winners were chosen and properly applauded for their ingenuity at a ceremony at the Ontario Science Centre, we set about to enlist partners in the venture, experts who could assist us in bringing the experiment to fruition.

If we were going to be successful we needed help from bread baking experts. The scientific and public relations value of our experiment sparked the curiosity of Maple Leaf Mills, who make Monarch Flour, and they generously signed on as partners in our unique venture. Their task, which they are ably performing, is to assist us in choosing the proper ingredients and environment for baking bread in space. But that's easy you say...it's just flour, yeast and water. It's not as simple as you think as our expert from Monarch Flour will explain later in the presentation.

Next, we had to find someone to build our "space oven". After scouting the scientific research community and seeking advice from space hardware experts, Telesat Canada was selected to join our team. Over the last year Telesat has worked long and hard on the intricacies of building a space oven that will not only bake bread, but can be flown safely and successfully in the compact Getaway Special cannister. You'll hear their very interesting story in a moment.

Like all Getaway Special experimenters, our triumvirate is very excited about the prospect of launching our experiment. Everything has been tested and retested and the space oven is now flight ready and being stored in a cleanroom at Telesat awaiting the next shuttle flight. In it we've baked experimental earth-bound loaves of bread and we're confident that the oven will do likewise in space. Needless to say, we anxiously await word from NASA that shuttle flights have resumed. At the moment the test hardware is on display at the Food Exhibit of the Ontario Science Centre in Toronto.

Now I take great pleasure in turning the platform over to Telesat Canada who are going to explain how you build a "space oven".

BUILDING THE EXPERIMENT'S APPARATUS

Introduction

Telesat undertook the design and manufacture of the experiment, drawing experience from the implementation of its satellite and Getaway Special programs.

The primary design goals were simplicity of operation, ease of assembly and utilization of standard parts without compromising system reliability. These goals were met, in some cases by the novel use of equipment, and the build program was completed in nine months. The initial planning for the program was, by necessity, flexible because so few of the design parameters were known; however, by setting decision points and exploring multiple design solutions a schedule could be maintained. This approach required manufacturing a development model, an engineering model and a protoflight model prior to the final flight version, each incorporating refinements to optimize performance.

Using the experience gained in satellite programs the worst case of thermal conditions were defined at +40°C and -15°C, which gave adequate margins over expected conditions, a power budget was prepared (based on oven power requirements) and a weight budget was prepared. With these parameters outlined and a conceptual design the development program was planned.

Development Summary

The guiding factor throughout the development program was maintaining simplicity of design without compromising reliability.

The original concept was to provide a baking chamber containing the flour/yeast mixture, a water container and a motor driven plunger to mix the flour, yeast and water, but before embarking on a design program, there were several unknowns that required quantifying. Unfortunately, it appeared that most problems in the baking field were solved empirically, so we embarked on our own development program.

The initial problem was how to mix the flour, yeast and water to form a dough effectively and minimize the power required for the mixing. There were no published figures showing the characteristics of dough, so a series of tests were performed using various designs of beaters, which culminated in the current spiral dough hook. This design meets the requirement of effective mixing with minimal power consumption. The original design concept consisted of a plunger driven linearly, similar to a piston; however tests showed 400 kg of force were required to mix the flour and water. In addition the mix was very poor because the plunger created a hard, dry pellet at the end of its stroke and left some free water.

Agriculture Canada provided a demonstration of the "stomacher" developed to mix food for the early astronaut programs. The stomacher used two alternating paddles which provided a very good mix; however, the use of a flexible sealed container was impractical for our application. A dual plunger linear system was tried, which provided an improvement over the single plunger, but still left a hard dry pellet. The linear motion approach was discarded in favour of rotary motion using blades similar to those of a food processor. This provided a good mix if it swept the length of the chamber, i.e., combining rotary and linear motion, however it required a high torque and its performance in micro-gravity was doubtful.

The final solution was to return to the system the bread industry used, the dough hook. The original version was fabricated from a wire coat hanger and produced perfect dough in 15 seconds with minimal torque. This ensured a miniature d.c. motor could be used and, based on the available space, the baking chamber size was determined.

Having selected a dough hook design and the baking chamber size, the next stage was to characterize the motor. This was achieved by selecting a variable speed high torque motor to drive the dough hook in the baking chamber. The torque loading characteristics for various chamber fill factors were determined so the motor could be sized to provide the required torque with minimum power consumption. There were two approaches to motor selection, a custom built model to optimize performance or a compromise on efficiency by obtaining a standard catalogue model. With the desired speed/torque characteristics defined it was found that there was a negligible difference in performance between a custom built and catalogue model, so the catalogue version was chosen for reasons of availability and cost.

With the motor and baking chamber sized, the next phase was to determine the thermal characteristics of the baking chamber. Two potential methods of heating the chamber were evaluated, one using a wrap-around silicon heater, the other cartridge heaters and thermostats embedded in the chamber walls. The engineering model used a 120 V wrap-around heater powered through a variable transformer which allowed the heat input to be varied, however, temperature control was a problem. A thermostat was impractical because of available locations so a thermistor was mounted on the chamber end plate and a control circuit designed to condition the thermistor output and switch the heater on and off.

The engineering model was subjected to environmental testing under worst case conditions ($-15^{o}C$) at various "dough" fill factors. The results showed that a good product could be obtained with a power input of 90 watts with almost zero soak back to the motor, which was the primary concern. In addition, the use of Fiberfrax ceramic fibre insulation ensured a long thermal decay which would continue to dry the product after active heating.

A trade-off analysis was performed on the two heater options and the embedded heaters/thermostats solution was chosen. Thermistors have guaranteed performance only up to $100^{o}C$ and the required operating temperature was $150^{o}C$. The thermistor resistance at this temperature was 4 ohms so the length of wiring to the control circuit affected the temperature control making this option impractical. There were the additional advantages of weight saving (control circuit and wiring not required) and simplicity which, when taken with the reliability aspect made the choice obvious.

The next step was to find a suitable water accumulator, the initial solution of a simple syringe being rejected was unreliable. Investigation showed that most fluid accumulators were used in high pressure hydraulic systems with working pressures in excess of 500 psi and were totally inappropriate for our application. Pneumatic control systems were found to use lightweight miniature cylinders and a suitable spring loaded cylinder was selected from the standard range available. Standard 1/4 inch plumbing fittings were used to connect the water cylinder to the baking chamber and a miniature pneumatic two port solenoid valve was incorporated to control the water injection.

A complete engineering model system was assembled using a breadboard control circuit used to bake bread. Operating the system showed that the sequence of events needed changing to optimize the mix consistency; the water had to be injected after the motor was started not before. A series of tests were run to verify the sequence times and the power budget adjusted accordingly.

The power budget allocation for the water heater required verifying so a low temperature test was conducted using a water accumulator charged with water, fitted with a heating pad and insulated with Fiberfrax. The assembly was installed in a thermal chamber and stabilized at the worst or low temperature. With a heat input of 30 watts it took seven minutes for the water accumulator to reach the target temperature $70^{o}C$, which verified the power budget allocation was adequate. The power budget had caused some concern because the initial power projections required the use of silver-zinc cells; however, by optimizing the design the power requirements were reduced sufficiently to use GATES 25 AH lead acid cells and provide sufficient margin for a three month period between experiment integration and on-orbit start up.

With potential of this three month integration period there was some concern over the ability of the plumbing to remain charged with water, therefore, a leak test was performed. A water accumulator, solenoid valve and associated plumbing were charged with water under pressure and used as the leak test assembly. The assembly was checked for visible leaks and change in position over a period of ten weeks. The cylinder showed no detectable leaks over this period, so was considered suitable for this application.

It was also believed that a helium leak test might provide a quick check on the integrity of the water accumulator, so one cylinder was subjected to a helium leak test and found to allow helium to leak around the piston seals at quite a high rate. In view of this, and the success of the cylinder on a test with water, the long term test was terminated and the cylinder subjected to a helium leak test. This cylinder also leaked helium, but at a lower rate than the new cylinder.

An attempt was made to determine a direct correlation between the helium leak rate and the equivalent water leak rate, but the resulting factor suggested the cylinder would lose all the water in 42 minutes so was disregarded.

The initial test was at ambient and it was discovered that the temperature rise was slow due to excessive thermal conduction through the end plates and brackets. The design was therefore modified by changing the end plates to teflon, which effectively stopped the conductive leakage.

Testing with the new configuration was carried out with ambients of $-15^{o}C$, $20^{o}C$ and $40^{o}C$ with no further problems. The results showed only minor differences in the temperature profiles and no noticeable difference in the final product.

Thermal tests and numerous baking trials finalized the timing and thermal requirements for the experiment, the impact being reflected by redirections in the power and weight budgets. With completion of the protoflight test program, the flight parts were purchased and the flight model assembled. The flight model was subjected to acceptance level vibration to verify the workmanship and was functioned at $-15^{o}C$ and $+40^{o}C$ to characterize performance. All tests were successful and the experiment has been sent for storage awaiting a flight.

SELECTING THE INGREDIENTS

We will introduce this portion of the presentation by describing the way bread is made traditionally and then show how the ingredients and the method had to be modified to make bread in space.

Let us first look at the main ingredients, flour and yeast. The flour used for bread in North America is made from Hard Red Spring wheat which has a high protein content, 13% to 14% and at the same time a very elastic gluten allowing it to retain gas bubbles. Gluten is the term used to describe the protein of the flour in bread making.

The type of yeast used in bakeries is so-called fresh yeast, which is a living organism which has to be refrigerated to keep it alive. Even so it only has a short life. There has been a move to Active Dry Yeast in recent years particularily in the home. This need not be refrigerated but has a life of about one year. The drawback of both these yeasts is that they have to be activated with water before mixing with the flour. Traditionally the yeast is mixed with warm water and this suspension is mixed with the flour. Small amounts of shortening, sugar and salt are also often added for texture and flavour development.

The dough then has to be mixed vigorously to start the fermentation. In a bakery, powerful mixers are used but in the home the dough has to be kneaded and rekneaded. The dough is then set aside for about one hour at 40°C to rise to double its volume. This is called proofing. Next it is "punched down" to eliminate large gas bubbles and then shaped into loaves and placed in a baking pan to again rise for about one hour. It is then baked at 175C for 30 to 45 minutes. The bread at this stage has a shelf life of only about one week. As you can see this type of process would not be practical for a Getaway Special experiment.

Fortunately there have been advances in making both flour and yeast in the past five years which have allowed us to adapt baking to fit the constraints of a Getaway Special experiment.

Ascorbic acid (vitamin C) and l-cysteine (an amino acid) can now be added to flour and these together remove the necessity for such vigorous mixing and at the same time remove the necessity for the first proofing stage. Thus the dough can be mixed and immediately shaped to fit the baking pan and then allowed to rise just once before baking.

There is also a new process for making active dry yeast which doubles its shelf life to two years when packed in nitrogen, but more importantly it does not need to be mixed with water first. Thus, it can be added to the flour in the dry stage to be activated when water is added to the flour.

If it were not for these two recent technological advances our Getaway Special experiment would not have been possible. The thought of an astronaut mixing flour, water and yeast in micro gravity conjures up a vision of a very dusty shuttle cabin.

The process we have devised to make the first bread in space is surprisingly very simple. Firstly, the flour is mixed with the yeast and sealed in the mixing chamber which is flushed with nitrogen. It now has a life of at least one year. As explained by Telesat, when the experiment is started, water is injected and the mixing started. Next the proofing stage starts and finally the baking takes place. In order to prolong the life of the bread the baking is longer than normal to remove most of the water, thus what we will end up with is a bread stick.

The success of this experiment, of course, is based on the assumption that yeast will work normally in micro gravity. Only when the experiment flies will we know whether our assumption is correct.

If everything goes as planned, who knows, we could be setting the stage for the first bread baked aboard the space station.